Robot Programming #15

Fundamental Electronics

Dept. of Mech. Robotics and Energy Eng.
Dongguk University

Introduction

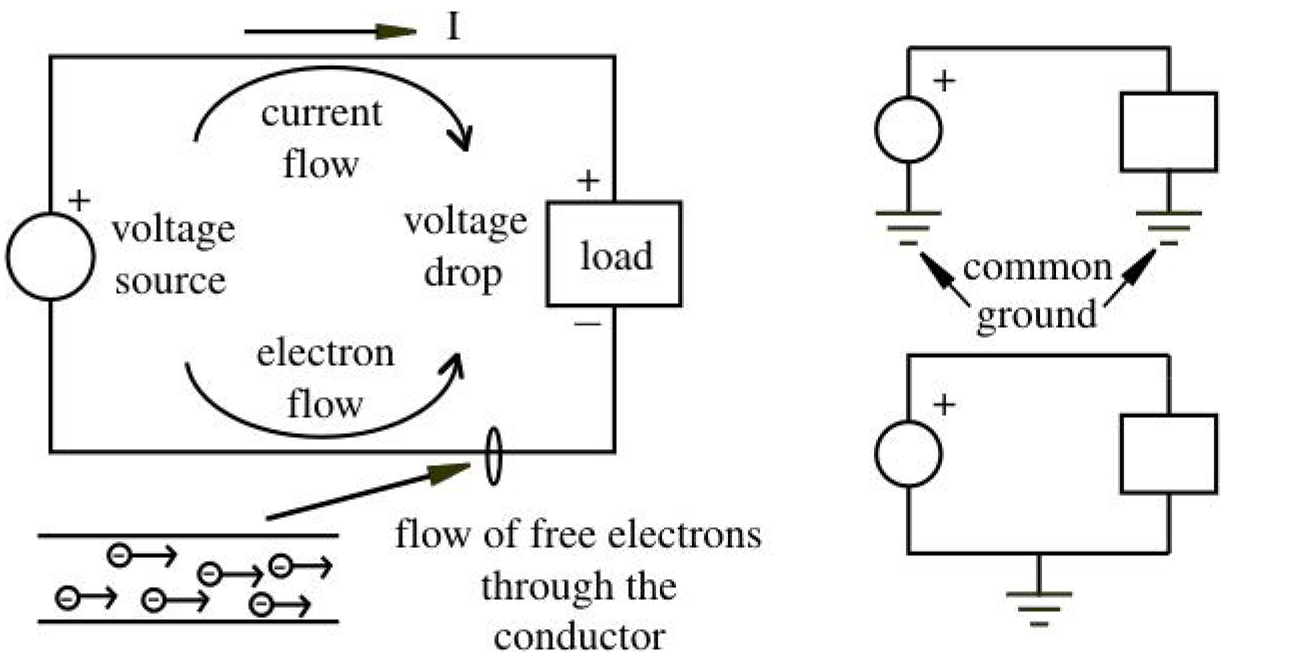
- Voltage: a measure of the electric field
- Current: the time rate of flow of charge

$$I(t) = \frac{dq}{dt}$$

- I: Current(A), q: quantity of charge(Coulomb)
- DC: direct current
- AC: alternating current

Introduction

- Electric Circuit

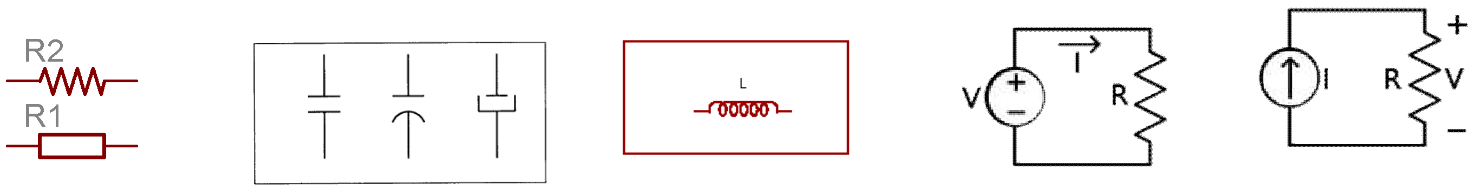


(a) Electric circuit

(b) Alternative schematic representations of the circuit

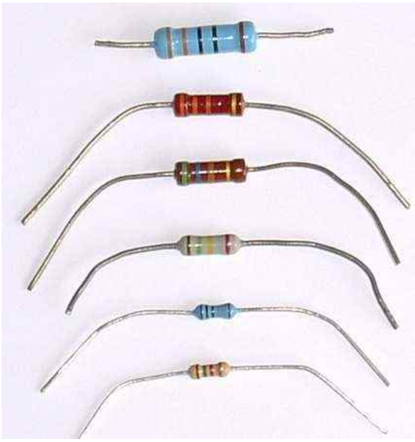
Basic Electrical Elements

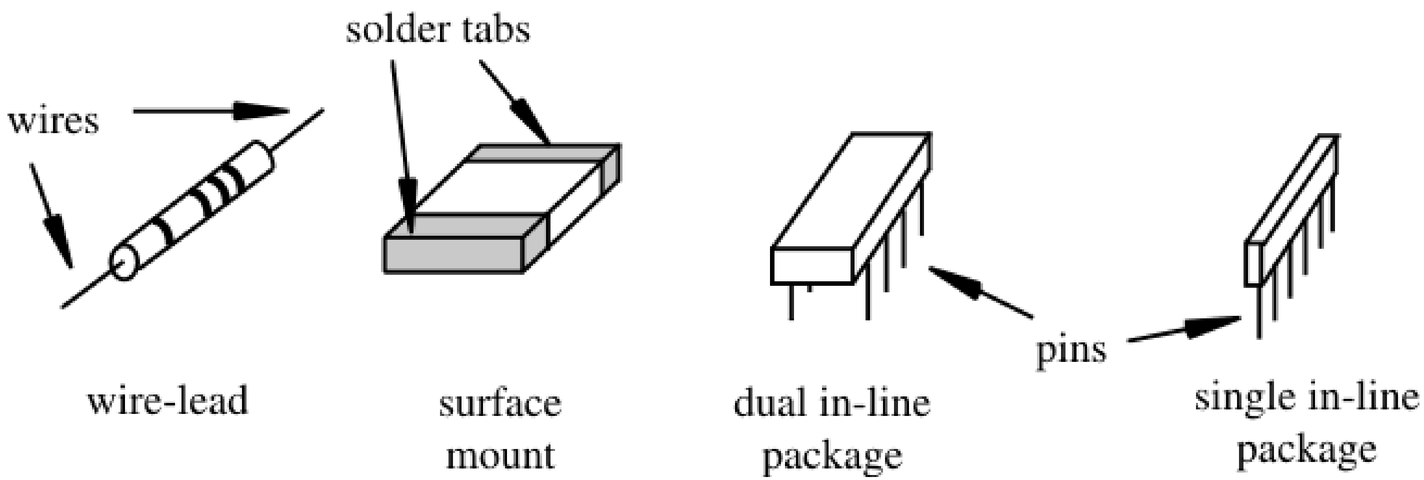
- Passive Elements:
  - Resistor(R)
  - Capacitor(C)
  - Inductor(L)
- Energy Sources:
  - Voltage source(V)
  - Current source(I)
- Schematic symbols



Resistor

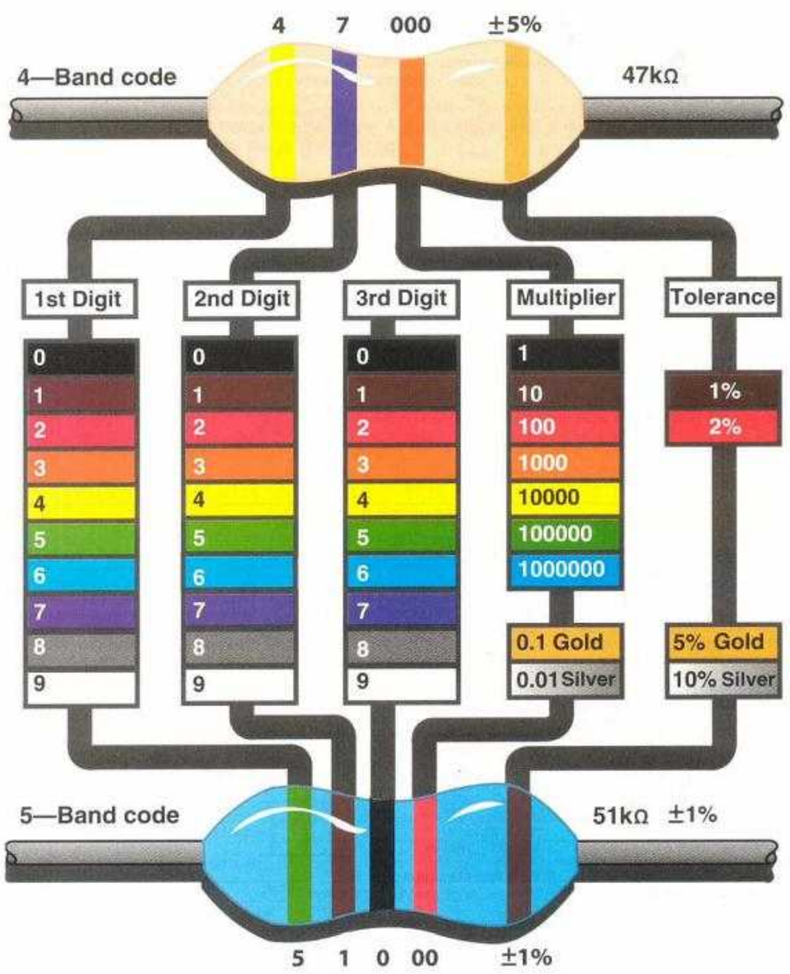
- Resistor: a dissipative element that converts electrical energy into heat
- Ohm's law: $\boxed{V = IR}$
- Unit: Ohm(Ω)
- Resistor Packaging





Resistor Color Bands

- Resistor Value: R=ab x 10^c +/- tolerance(%)

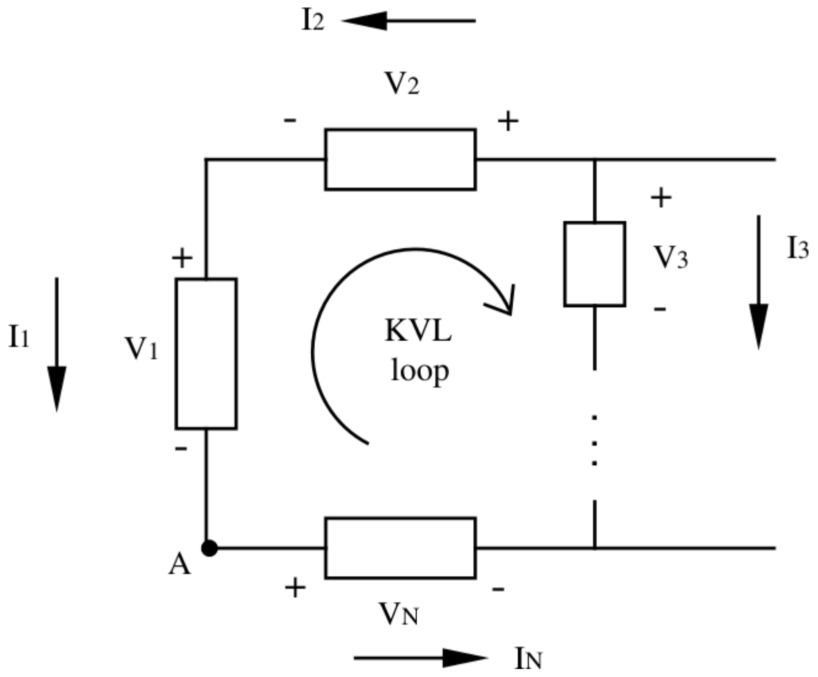


Resistor Color Code Example

1. Red, brown, yellow, gold = ? Ω
2. Orange, black, red, gold = ? Ω
3. Brown, black, red, gold = ? Ω
4. Red, green, brown, silver = ? Ω
5. 100 kΩ = color code?
6. 100 Ω = color code?
7. 470 Ω = color code?
8. 33 MΩ = color code?

Kirchhoff Voltage Law

- Kirchhoff's voltage law: The sum of voltages around a closed loop or path is zero.

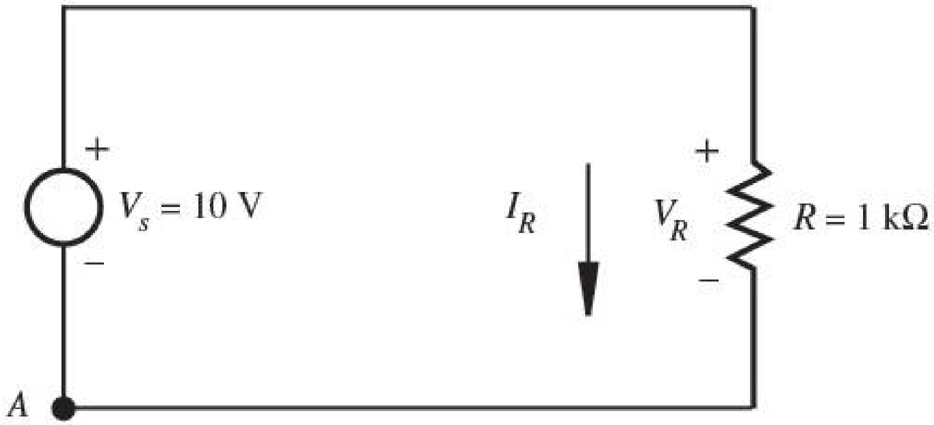


$$-V_1 - V_2 + V_3 + \cdots - V_N = 0$$

- Kirchhoff's voltage law: $\sum_{i=1}^{N} V_i = 0$

Kirchhoff Voltage Law

- KVL Example: $I_R = ?$



- Starting at point A and progressing clockwise around the loop,

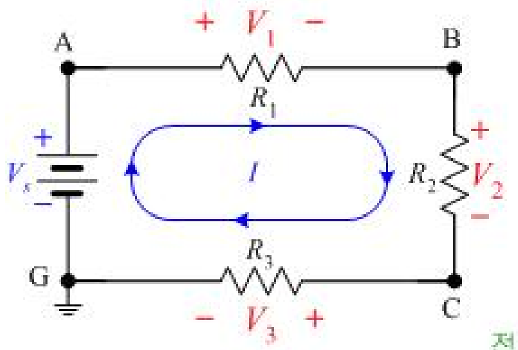
$$V_s - V_R = 0$$

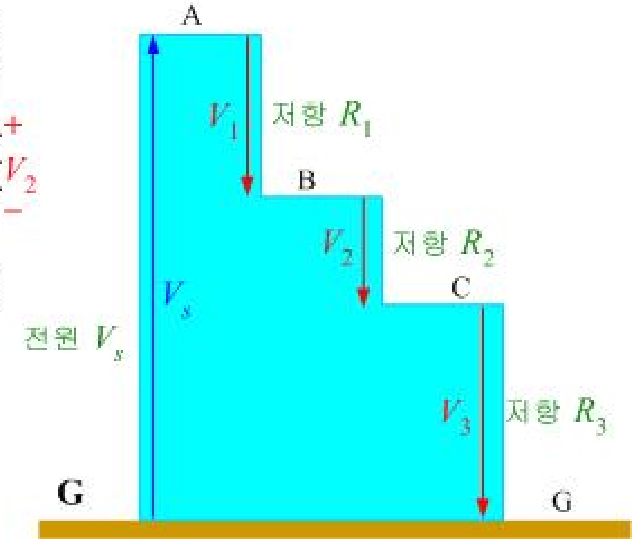
- Applying Ohm's Law, $V_s - I_R R = 0$
- Therefore,

$$I_R = V_s / R = 10 / 1000\,\text{A} = 10\,\text{mA}$$

Kirchhoff Voltage Law

- Application of KVL





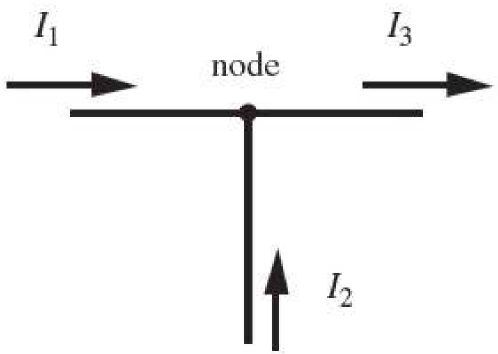
- KVL: $$\sum_{i=1}^{N} V_i = 0$$

  - Application of KVL: $$+V_s - (V_1 + V_2 + V_3) = 0$$

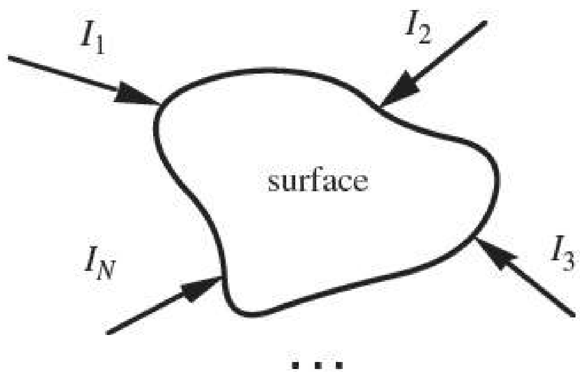
$$+V_s - (IR_1 + IR_2 + IR_3) = 0 \qquad I = V_s / (R_1 + R_2 + R_3)$$

Kirchhoff Current Law

- Kirchhoff's current law: The sum of the currents flowing into a closed surface or node is 0. For the following figure, $I_1 + I_2 - I_3 = 0$



(*a*) Example KCL

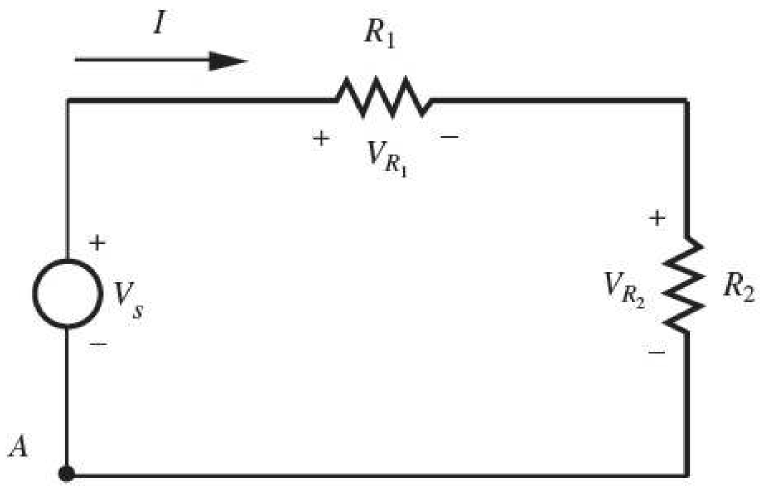


(*b*) General KCL

- Kirchhoff's current law: $\sum_{i=1}^{N} I_i = 0$

Series Resistance Circuit

- Applying KVL to the simple series resistor shown below,



$$+V_s - V_{R_1} - V_{R_2} = 0 \qquad (1)$$

- From Ohm's Law, $V_{R_1} = IR_1 \qquad V_{R_2} = IR_2$ (2)

Series Resistance Circuit

- Inserting Eq. (2) into Eq. (1),

$$+V_s - IR_1 - IR_2 = 0$$

- Solving for I ,

$$I = \frac{V_s}{\left(R_1 + R_2\right)}$$

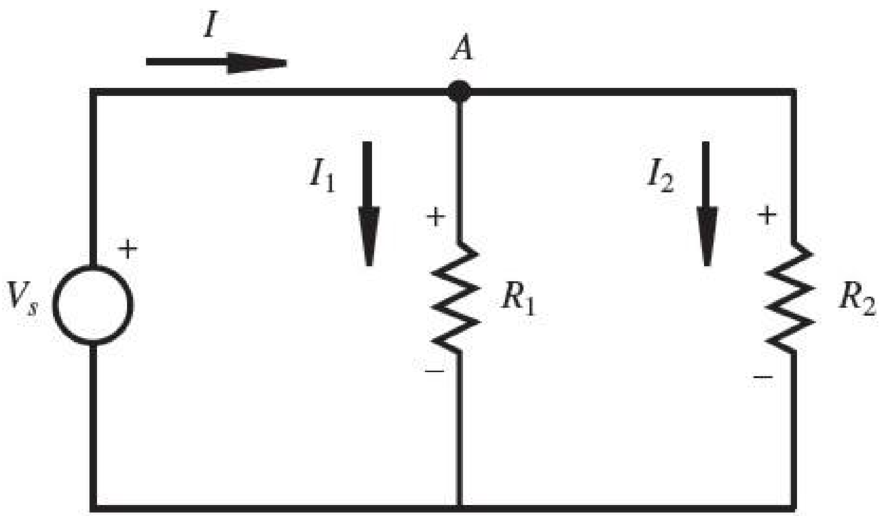
- Equivalent resistor, $R_{eq} = R_1 + R_2$

- In general, N resistors connected in series can be replaced by a single equivalent resistance given by

$$R_{eq} = \sum_{i=1}^{N} R_i$$

Parallel Resistance Circuit

- Applying KCL at node A of the circuit below and using Ohm's law,



$$I - I_1 - I_2 = 0$$

$$I_1 = V_s / R_1, \quad I_2 = V_s / R_2$$

- Using the above Eqs.,

$$I = V_s \left(\frac{1}{R_1} + \frac{1}{R_2} \right) = \frac{V_s}{R_{eq}}$$

Parallel Resistance Circuit

- Equivalent resistance:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$$

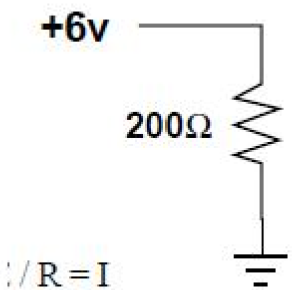
- General formula:

$$R_{eq} = 1 / \sum_{i=1}^{N} \frac{1}{R_i}$$

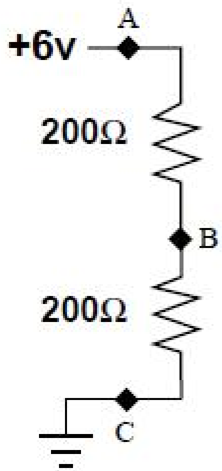
Practice Examples:

- Calculate the current:

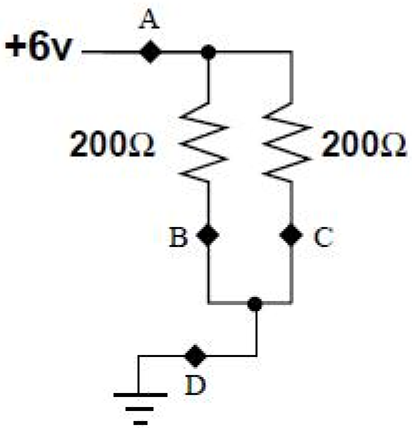
(a)



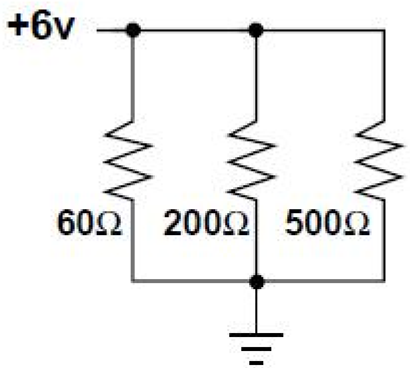
(b)



(c)

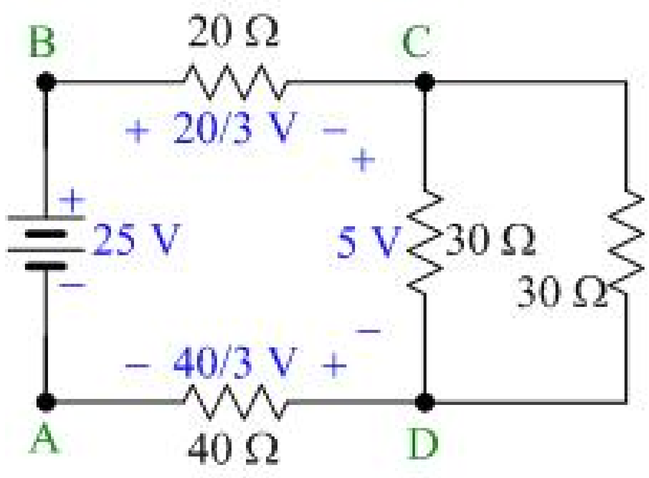


(d)

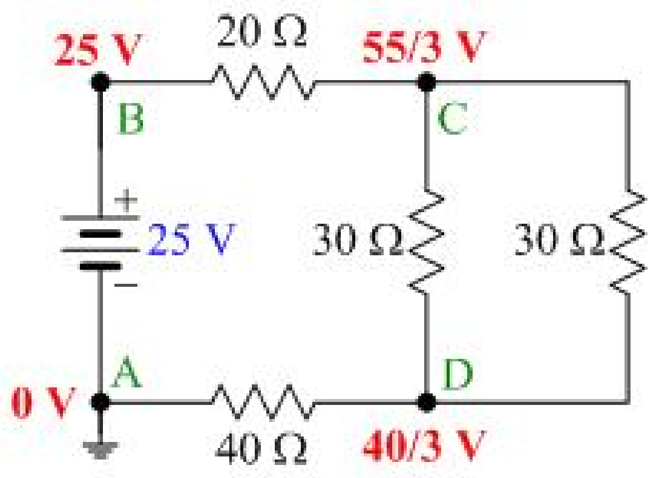


Ground

- Field Difference(Difference in Electrical Energy)
  - The potential and electrical energies in space cannot be defined as absolute value but can be measured by relative value.
- Ground
  - Can make the node have the reference voltage(0V) if it is connected to the earth.

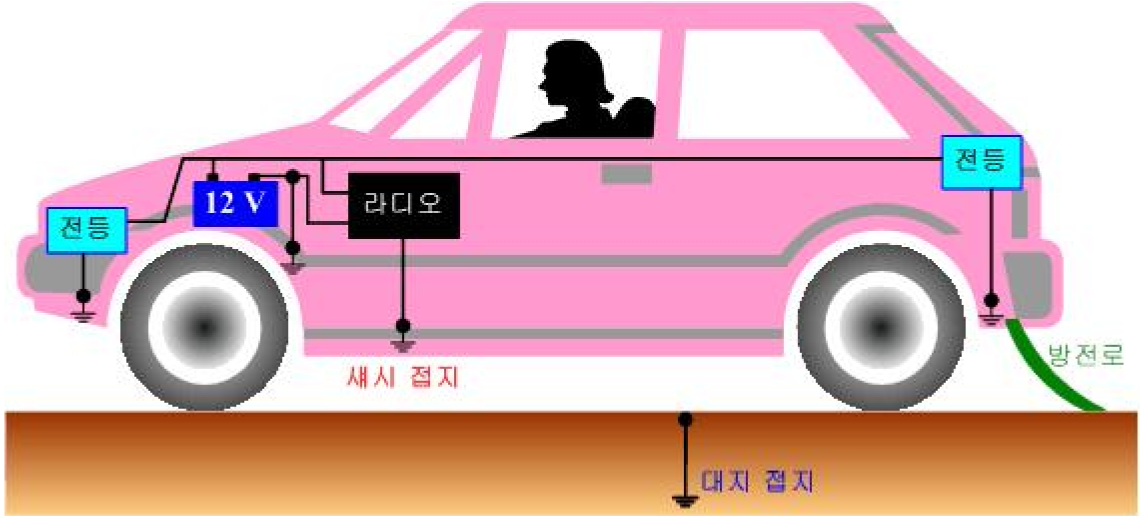


(a)

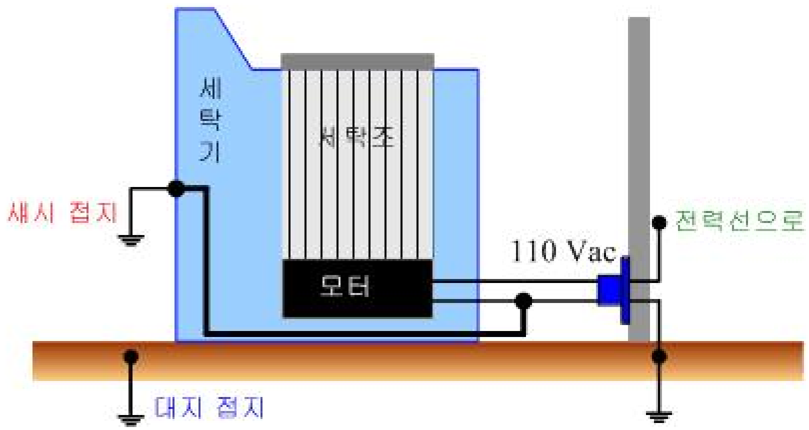


(b)

Grounding Examples



(a)

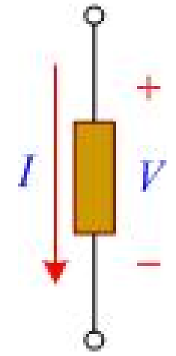


(b)

Power

- Amount of work per a given period of time(W)

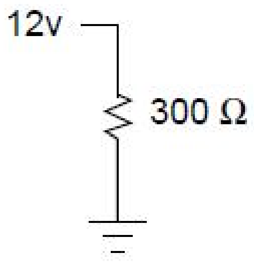
$$P=\frac{\text{Work}}{\text{Time}}=\frac{\text{Work}}{\text{Unit Charge}}\times\frac{\text{Unit Charge}}{\text{Time}}=\text{Voltage}\times\text{Current}$$



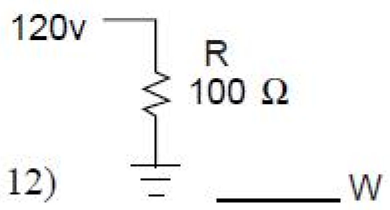
$$P=VI=I^2R=\frac{V^2}{R}$$

Power Example

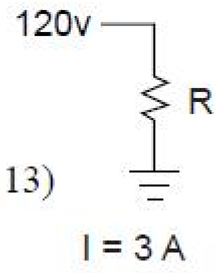
(a) I=?, P=?



(b) I=?, P=?



(c) R=?, P=?



Capacitor & Inductor

- Capacitor: a passive element that stores energy in the form of an electric field.
- Consists of a pair of parallel conducting plates separated by a dielectric material.
- $I(t) = C\,dV/dt$

- Inductor: a passive energy storage element that stores energy in the form of magnetic field.
- $V(t) = L\,dI/dt$

Alternating Current Analysis

- When linear circuits are excited by alternating current(AC) signals of a given frequency, the current through and voltage across every element in the circuit are AC signals of the same frequency.
- A sinusoidal AC voltage V(t) is illustrated as follows:

$$V(t) = V_m sin(\omega t + \phi)$$

V_m :Signal Amplitude, ω :radiation frequency

ϕ :phase angle , $\phi = \omega \Delta t$, Δt :time shift

$$f = \frac{1}{T} = \frac{\omega}{2\pi} \quad (\mathrm{Hz})$$

Generalized Ohms Law

- Voltage and Current:

$$V(t) = V_m e^{j(\omega t+\phi)},\ v(t) = V_m cos(\omega t + \phi) = \mathrm{Re}[V(t)]$$

$$I(t) = I_m e^{j(\omega t+\psi)},\ i(t) = I_m cos(\omega t + \psi) = \mathrm{Re}[I(t)]$$

- Complex Impedance:

$$Z(t) = \frac{V(t)}{I(t)} = \frac{V_m e^{j(\omega t+\phi)}}{I_m e^{j(\omega t+\psi)}} = \frac{V_m}{I_m} e^{j(\phi-\psi)}$$

Generalized Ohms Law

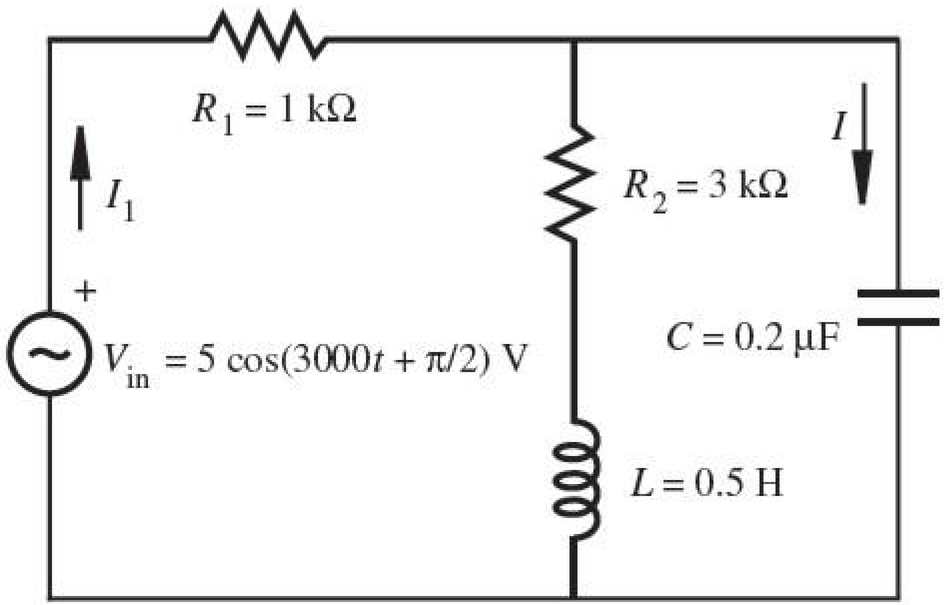
- Instead of resistor, capacitor, and inductor, we use impedance.

$$V = ZI$$

- for resistor: $Z_R = R$
- for inductor: $Z_L = j\omega L$
- for capacitor: $Z_C = \dfrac{1}{j\omega C}$

AC Circuit Analysis

- Find the steady state current I through the capacitor in the following circuit.

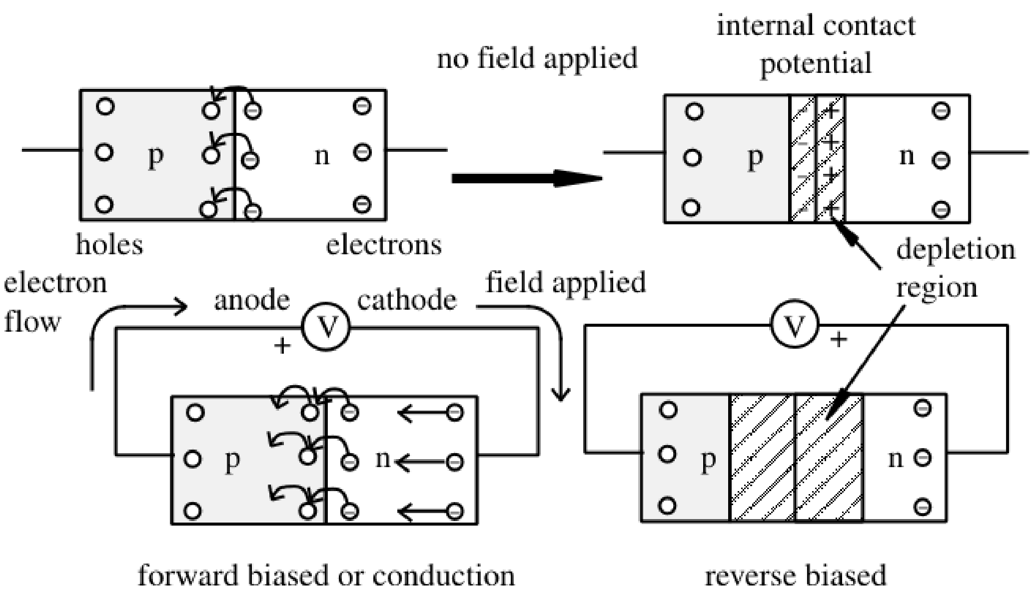


Semiconductor Physics

- Conductor: (a metal such as copper) large current can flow easily
- Insulator: (glass) the electrons do not move easily
- Semiconductor: (Silicon & Germanium) current-carrying characteristics depend on temperature or the amount of light falling on them
- The properties of pure semiconductor crystal can be significantly changed by inserting small quantities of elements(dopants)
- Donor: enhances the electron conductivity -> n-type
- Acceptor: holes form due to missing electrons. Electrons move to occupy the holes. -> p-type

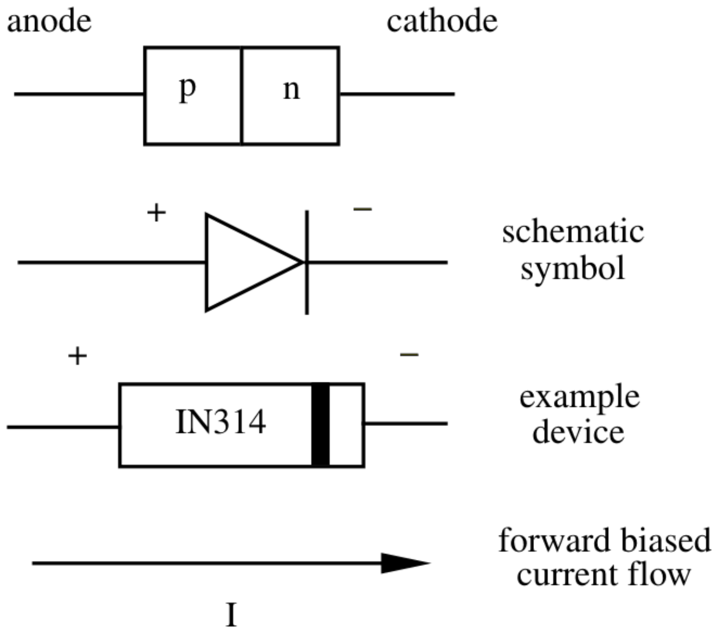
Junction Diode

- pn junction: p-type region of silicon is created adjacent to an n-type region.
- electrons from the n-type silicon can diffuse to occupy the holes in the p-type silicon, creating a depletion region.

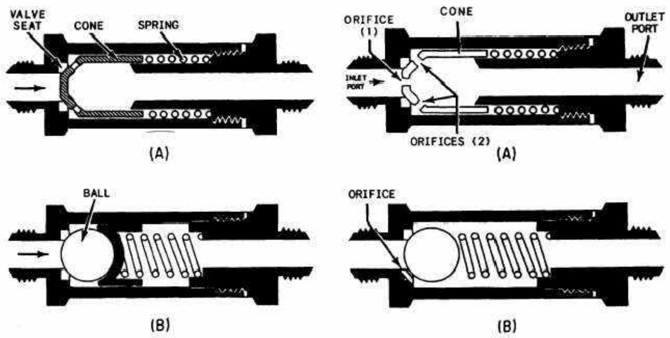


Junction Diode

- Silicon Diode:

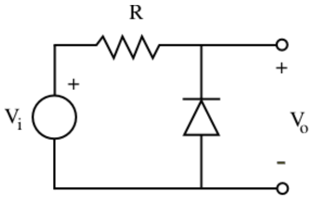


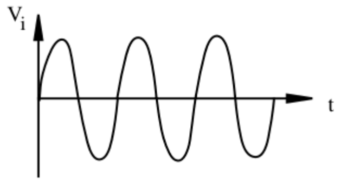
- similar to check valve

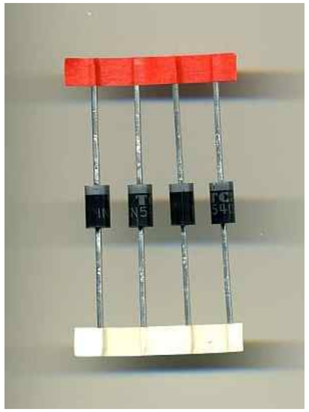


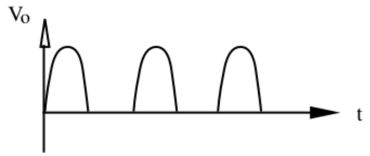
Types of Diodes

- Small Signal: used to transform low current AC to DC, detect(demodulate) radio signals, multiply voltage, perform logic, absorb voltage spikes.





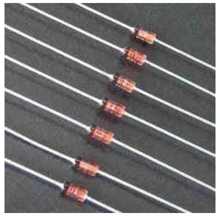




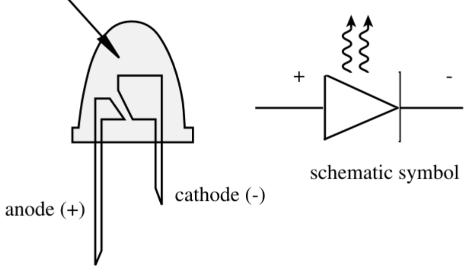
- Power Rectifier: similar to the above, except that it can handle large current. used in power supplies, AC/DC conversion.

Types of Diodes (Continued)

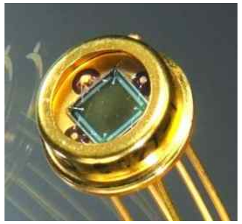
- Zener: has a specific reverse breakdown voltage. used as a voltage sensitive switch, and constant current power supplies.



- LED: emit some electromagnetic radiation when forward biased.



- Photo diodes: detect light



Voltage Regulators

- Zener diode voltage regulator is cheap and simple to use. But it has drawbacks: the output voltage cannot be set to a precise value, and regulation against source ripple and changes in load is limited.
- Special semiconductor devices are designed to serve as voltage regulator

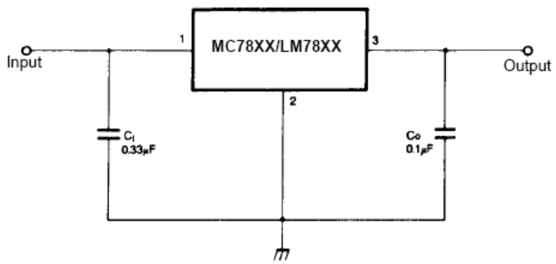
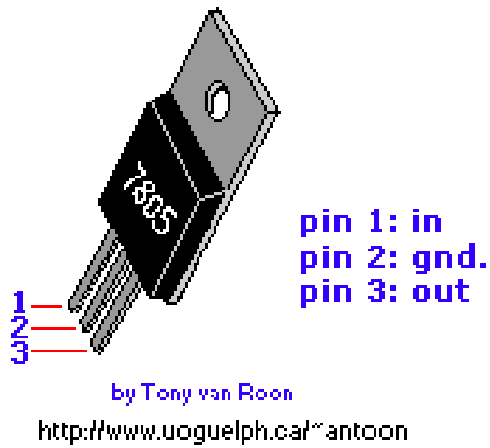
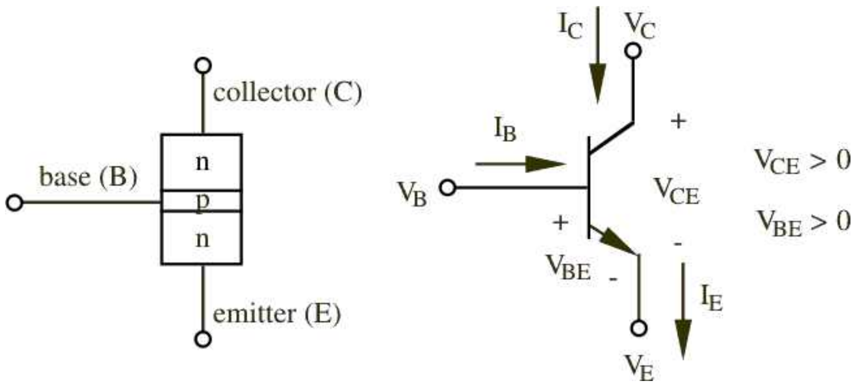


Figure 5. DC Parameters



Bipolar Junction Transistor

- npn transistor



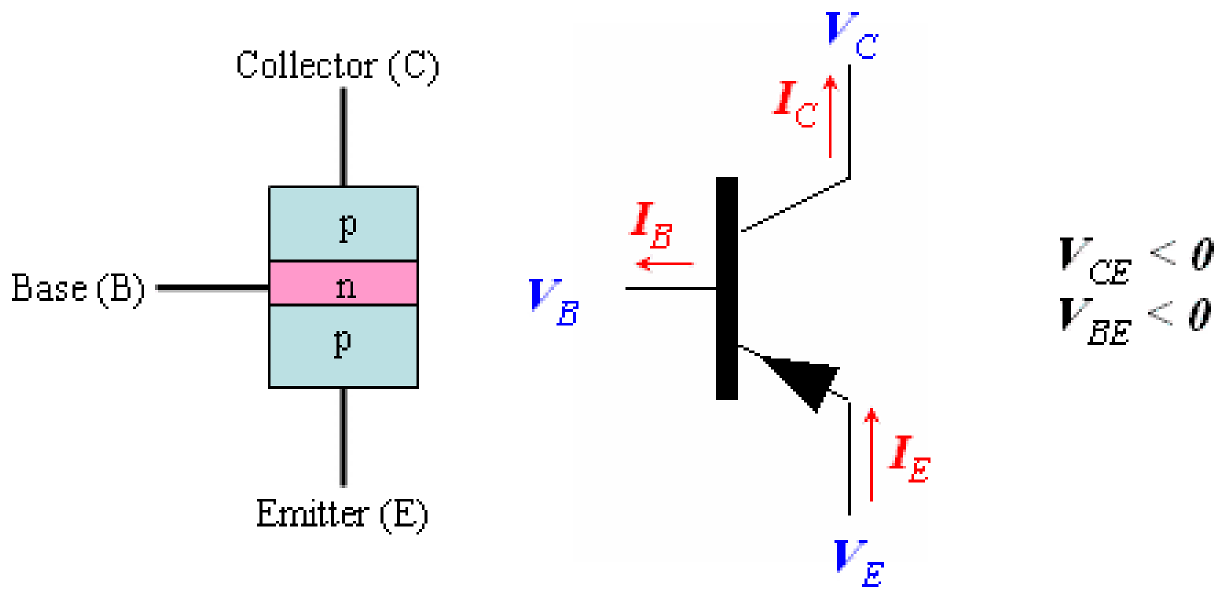
- The relationship between the base current and the collector current is given by:

$$I_C = \beta I_B, \ (\beta > 100)$$

- Transistor functions as a current amplifier.

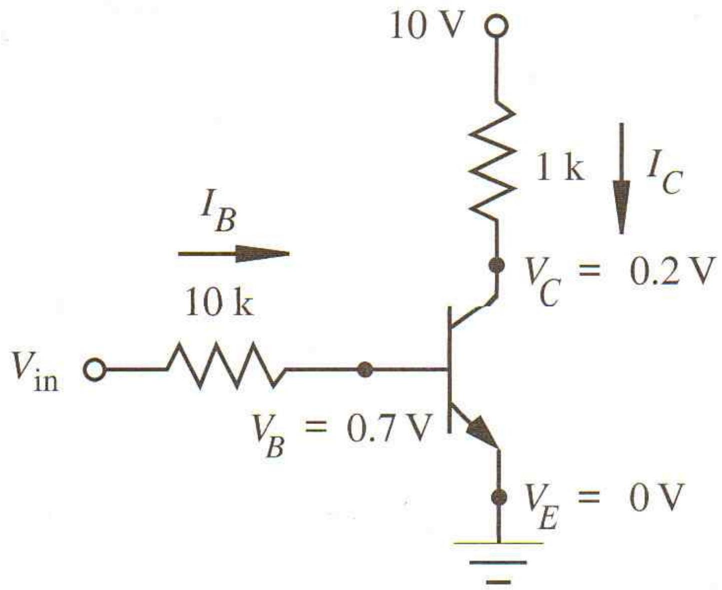
Bipolar Junction Transistor

- In the case of the pnp transistor, the base and the collector current flow out of the transistor and the collector-emitter voltage is reversed.



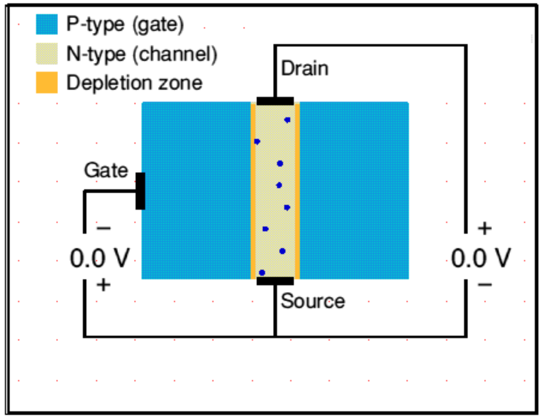
Example: Transistor in Saturation

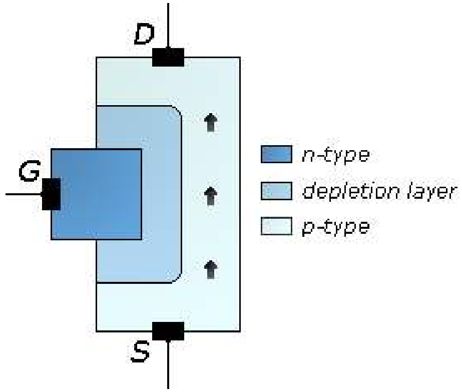
- $I_C = (10V - 0.2V) / 1k\Omega = 9.8mA$
- $I_B = I_C / \beta = 9.8mA/100 = 0.098mA$
- $I_B = 0.098mA = (V_{in} - 0.7V) / 10k\Omega$
- $V_{in} = 0.98V + 0.7V = 1.68V$



Field Effect Transistor(FET)

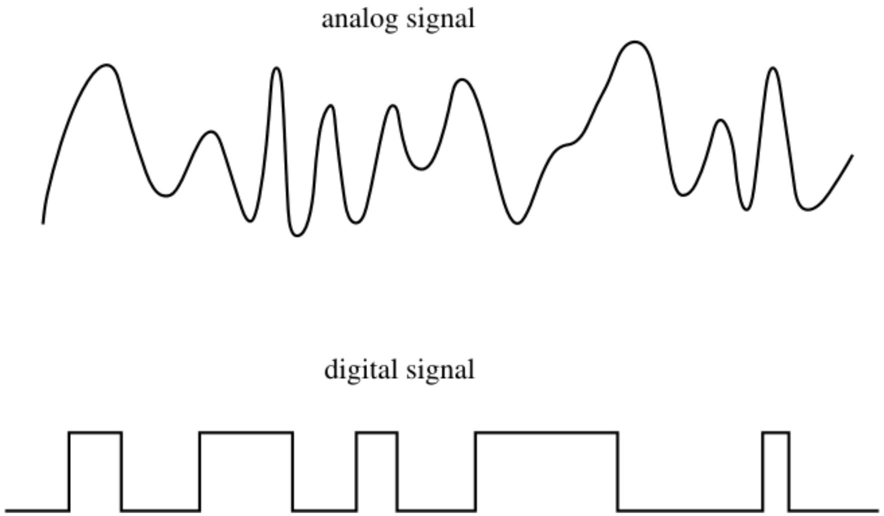
- easy to make and requires less silicon.
- two major FET families:
  - Junction(JFET)
  - Metal-Oxide-Semiconductor(MOSFET)
- The output current is controlled by a small input voltage and practically no current.
- The channel is like a transistor that conducts current from source to the drain.





Analog vs. Digital

- In contrast to an analog signal, a digital signal exists only at specific levels or states and changes its level in discrete steps.



- Digital signals have only two states: high and low
- Two state signals -> Boolean logic and binary number representation

Digital Representations

- the base 10 decimal number system:

$$\boxed{123 = 1\times10^2 + 2\times10^1 + 3\times10^0}$$

- binary number system:

$$\boxed{1101_2 = 1\cdot2^3 + 1\cdot2^2 + 0\cdot2^1 + 1\cdot2^0 = 8_{10} + 4_{10} + 0 + 1_{10} = 13_{10}}$$

- bits: the digits of a binary number

Digital Representations

- Decimal to binary conversion ($123_{10} \rightarrow ?_2$)

Successive divisions	Remainder	
123/2	1	LSB
61/2	1	
30/2	0	
15/2	1	
7/2	1	
3/2	1	
1/2	1	MSB
Result	1111011	

- Binary arithmetic is analogous to decimal arithmetic.

Digital Representations

- Hexadecimal(base 16) number system: 0~9, A~F

Table 6.2 Hexadecimal symbols and equivalents

Binary	Hexadecimal	Decimal
0000	0	0
0001	1	1
0010	2	2
0011	3	3
0100	4	4
0101	5	5
0110	6	6
0111	7	7
1000	8	8
1001	9	9
1010	A	10
1011	B	11
1100	C	12
1101	D	13
1110	E	14
1111	F	15

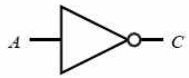
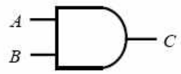
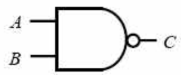
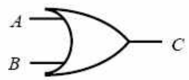
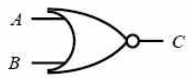
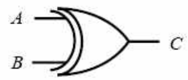
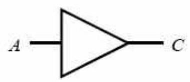
- Ex:

$$\boxed{123_{10} = 0111\,1011_2 = 7B_{16}}$$

Combinational Logic

- convert binary inputs to binary outputs based on the rules of mathematical logic.

Table 6.3 Combinational logic operations

Gate	Operation	Symbol	Expression	Truth table
Inverter (INV, NOT)	Invert signal (complement)		$C = \bar{A}$	A C 0 1 1 0
AND gate	AND logic		$C = A \cdot B$	A B C 0 0 0 0 1 0 1 0 0 1 1 1
NAND gate	Inverted AND logic		$C = \overline{A \cdot B}$	A B C 0 0 1 0 1 1 1 0 1 1 1 0
OR gate	OR logic		$C = A + B$	A B C 0 0 0 0 1 1 1 0 1 1 1 1
NOR gate	Inverted OR logic		$C = \overline{A + B}$	A B C 0 0 1 0 1 0 1 0 0 1 1 0
XOR gate	Exclusive OR logic		$C = A \oplus B$	A B C 0 0 0 0 1 1 1 0 1 1 1 0
Buffer	Increase output signal current		$C = A$	A C 0 0 1 1